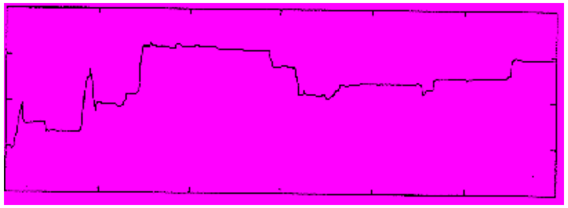
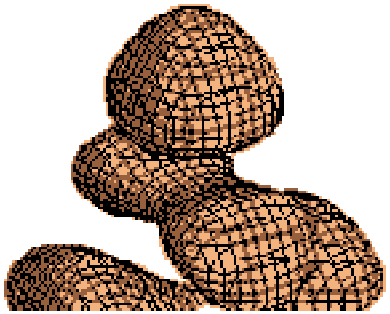
# Quantum Trajectory Methods for Simulating Solid-State Qubit Systems

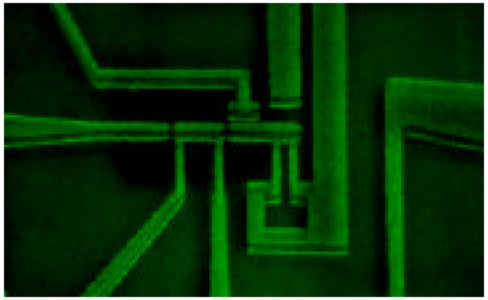
*Jonathan P. Dowling, QCT Group, NASA JPL, Caltech*
Jonathan.P.Dowling@jpl.nasa.gov / cs.jpl.nasa.gov/qct/qat.html

## Objective

- Collaborative Effort with Australian Centre for Quantum Computer Technology
- Single Electron Transistor Development
- Theory of Measurement of Mesoscopic Open Quantum Systems







## Objective Approach

- Matching Funds from Australian Gov't
- Exchange of Scientific Personnel
- Develop General Open Quantum System Approach to RF-SET Modelling and Design
- Quantum Trajectories Approach
- RF-SET Simulator
- Ab initio simulations of RF-SET

## Status

- NSA/ARDA Funding Committed
- Australian IREX Matching Funds
- Exchange of Senior Personnel Planned

# TEAMING & PARTNERING

CENTRE FOR QUANTUM COMPUTER TECHNOLOGY
AUSTRALIAN RESEARCH COUNCIL SPECIAL RESEARCH CENTRE

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

G. J. Milburn

UNSW

R. G. Clark

JPL

QUANTUM
Computing Technologies Group
J. P. Dowling

Micro-Devices Lab
P. M. Echternach

Collateral Collaborations
P. M. Alsing, UNM
A. Korotkov, UC-Riverside
G. Klimeck, JPL

# ROADMAP

**SET Design Tool**

**Experimental Comparison**

**Quantum Trajectory Simulations**

**Models of SET**

# MOTIVATION
## DiVincenzo Commandments with Upgrade*

I. Identification of well-defined qubits.
II. Reliable initial state preparation.
III. Low decoherence rate per gate operation.
IV. Accurate quantum gate operations (modulo error correction).
**V. High efficiency, strong quantum measurements.**

VI. All resources required scale polynomially with number of qubits.
VII. Decoherence and error rates per qubit constant with increasing numbers of qubits.
VIII. Ability to perform computations in parallel physical circuits.
**IX. Fast absolute clock speed.**
X. Encode in decoherence-free subspaces, when possible.

* 5–10 collected/suggested by JPD and D. F. V. James

# V & IX $\supset\!\!\longrightarrow$ THOU SHALT USE RF-SET!
# (For Most Scaleable Solid-State QC Schemes)

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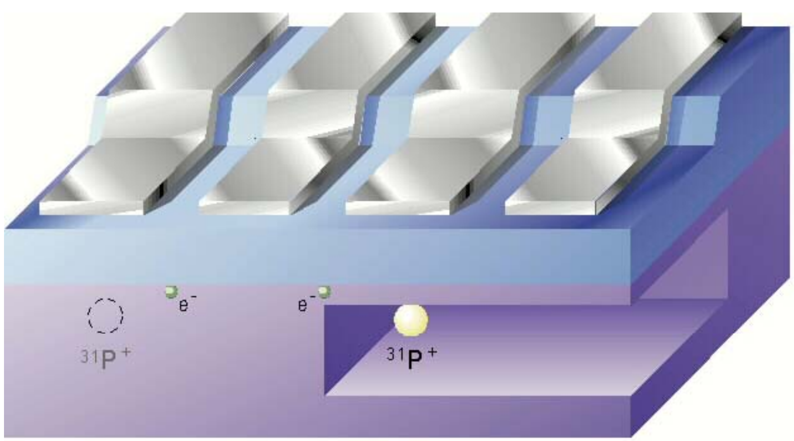
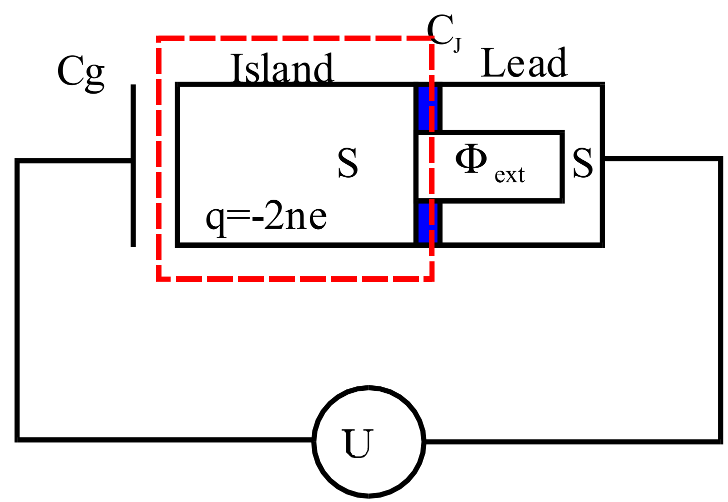
JPL

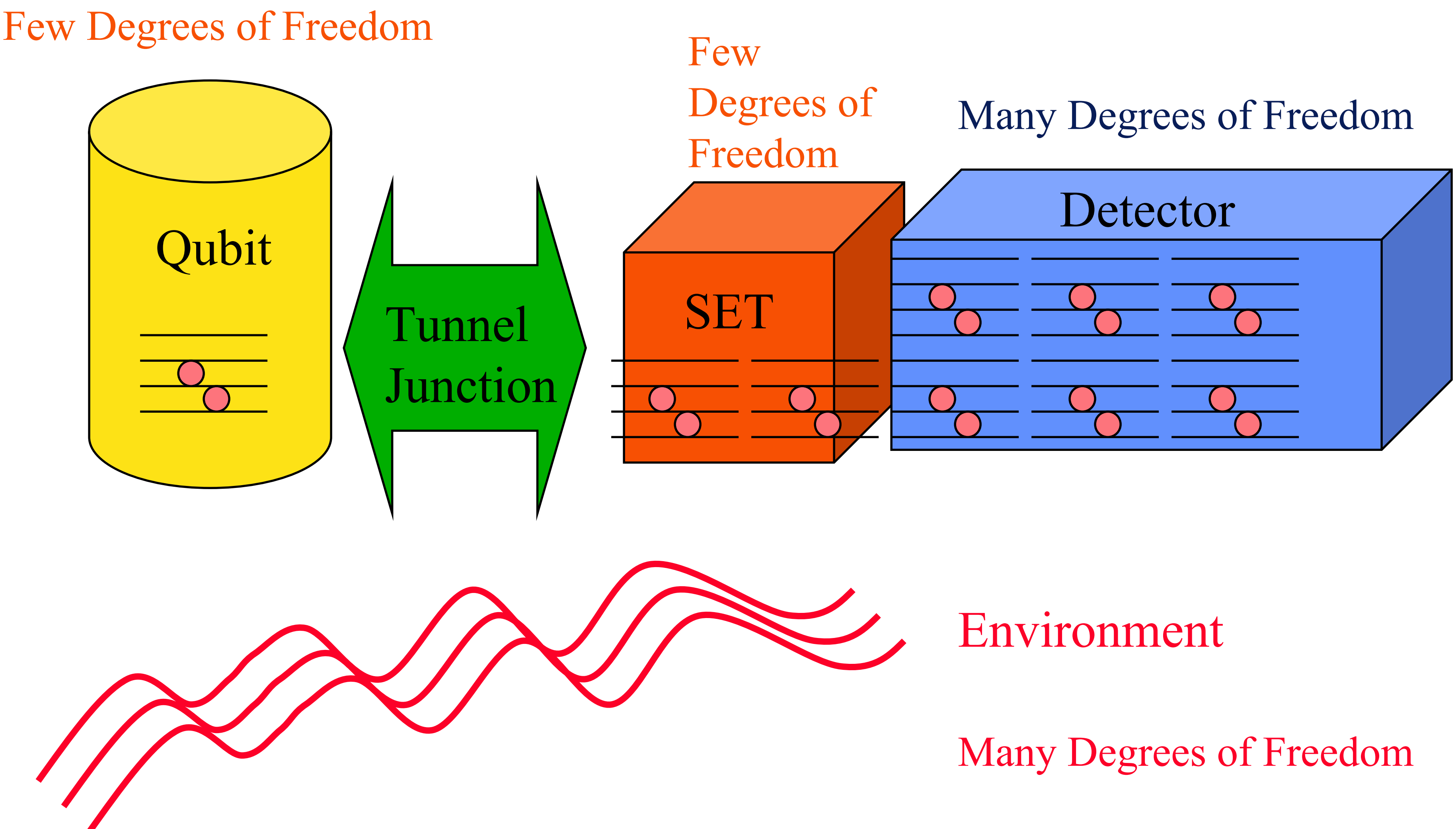



Kane Scheme
Spin to Charge to RF-SET




Nakamura Scheme
Cooper Pair to RF-SET

# GENERIC MODEL OF MESOSCOPIC QUBIT WITH RF-SET READOUT



# MASTER EQUATION FOR OPEN QUANTUM SYSTEMS

Time Evolution of Open Quantum System

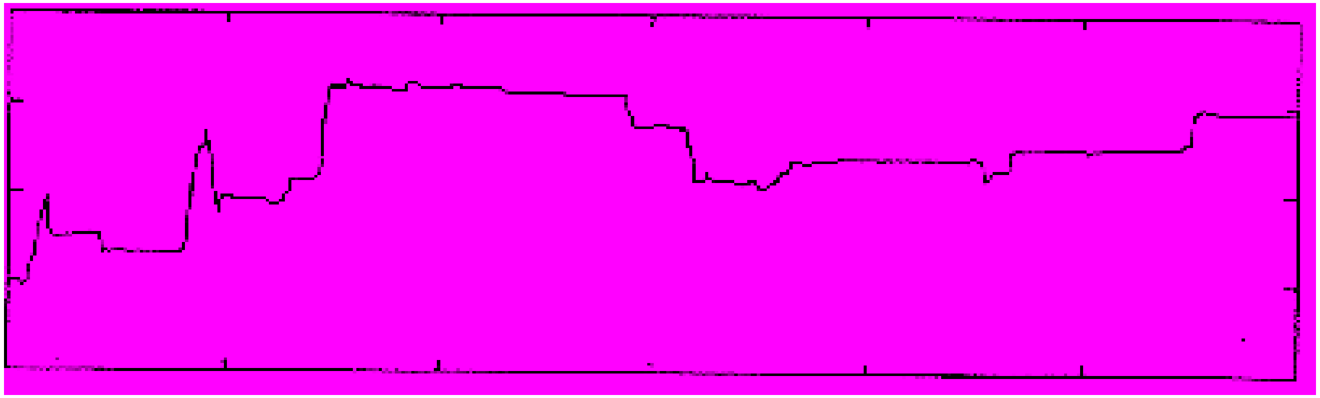
$$i\hbar \frac{d\rho(t)}{dt} = \left[H, \rho(t)\right] + \lambda\rho(t)$$

$\rho(t)$ = density matrix
H = Hamiltonian
$\lambda$ = functional of coupling constants

Traditional Numerical Method of Solution Scales Unfavorably as $N^2$ in Memory Usage

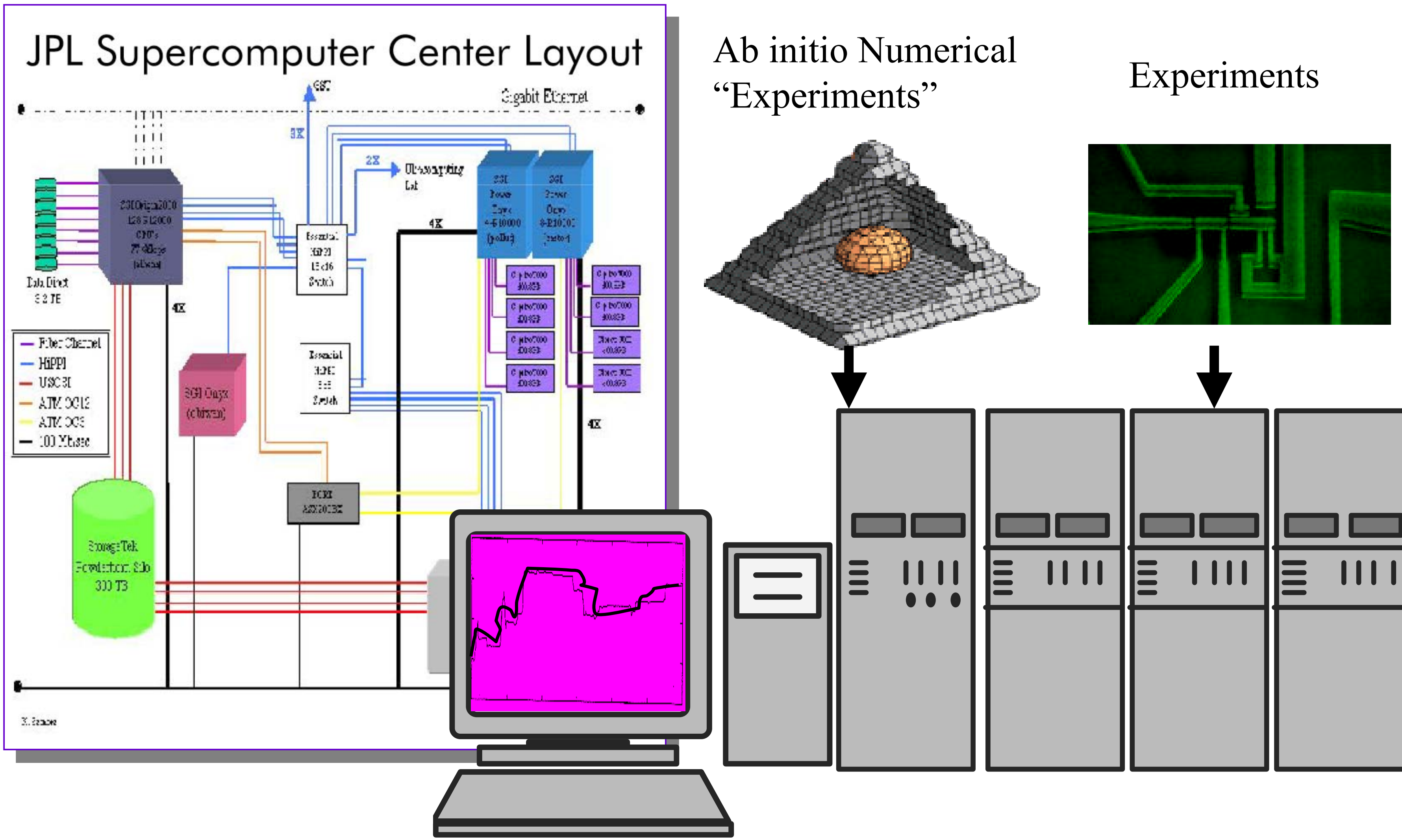
# QUANTUM TRAJECTORY APPROACH
## Trading Computational Memory for Speed

### Breakthrough Numerical Technique from Quantum Optics

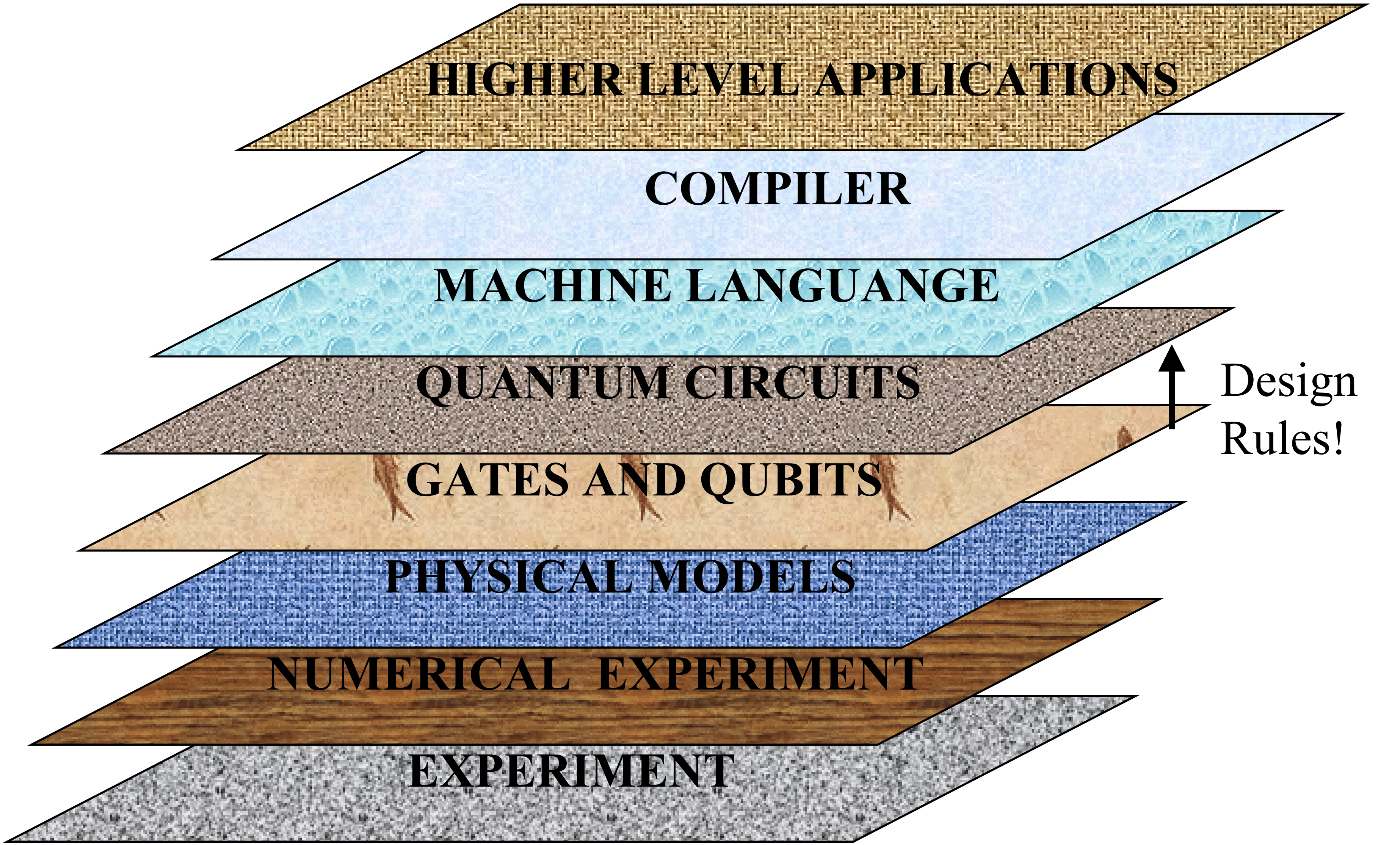


“The wave function simulation of the master equation replaces the solution for the $N^2$ density matrix elements by simulating the conditional time evolution of a system wave function(dimension N) interrupted by a sequence of quantum jumps. The ensemble distribution can be estimated to any precision by numerically averaging a sufficient number of simulated quantum trajectories.”

# LARGE-SCALE COMPUTATIONS AND SIMULATION TOOLS



# SCALABLITY IN QUANTUM COMPUTING: THE BIG PICTURE



# Research Plan

## Radio-Frequency Single-Electron Transistors and Measurement Of Mesoscopic Open Quantum Systems

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• Research plan for the next 12 months

- Exchange Visits of Senior Personnel
- Develop Mesoscopic Open Quantum System Models for RF-SET Used in Kane and Nakamura Schemes
- Develop Computational Code for Quantum Trajectory Simulations of Relevant Master Equations
- Compare Theory to Experiment and Numerical Ab Initio Calculations

• Long term objectives (demonstrations)

- Develop RF-SET Design and Test Tool
- Model RF-SET Arrays / Compare with Experiment
- Study of Scalable Architectures and Design Rules